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ACALYPTRATE DIPTERA ASSOCIATED WITH WATER WILLOW, *JUSTICIA AMERICANA* (ACANTHACEAE)

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Abstract.—The temporal distribution of 28 species of acalyptrate Diptera associated with water willow, *Justicia americana* (L.) Vahl, from northeastern Ohio and western Pennsylvania are given. Monocultural stands in three streams were sampled. Some species used the plant directly for food or respiration, whereas others utilized the sediments, detritus, algae, and microbes present among the rhizomes and roots. Three species of shore fly (Ephydridae), *Hydrellia griseola* (Fallén), *Notiphila carinata* Loew, and *Parydra quadrituberculata* Loew, and the stem-boring agromyzid, *Melanagromyza dianthereae* (Malloch), dominated numerically. The temporal distribution of the dominant species varied between sites, demonstrating that similar vegetation at different sites does not necessarily support identical dipteran communities. Biological observations on *M. dianthereae* are given.

Key Words: Macrophytes, *Justicia*, Ephydridae, Agromyzidae, *Melanagromyza dianthereae*, streams

Diptera frequently are the dominant group of animals encountered in marshes (e.g. Davis and Gray 1966; Scheiring and Foote 1973; Todd and Foote 1987a, 1987b; Larson and Foote 1997). Lush stands of emergent macrophytes provide a complex three dimensional habitat that harbors diverse insect communities (e.g. Todd and Foote 1987a).

Justicia americana (L.) Vahl is a dicotyledon that grows in shallow waters of intermediate-sized streams in northeastern North America. A few investigators have studied the life history of certain Diptera associated with *J. americana* (Malloch 1920, Deonier et al. 1979), but no comprehensive list of Diptera associated with this macrophyte has been compiled. Herein, we present the results of a survey of the acalyptrate Diptera taken from *J. americana* in northeastern Ohio and western Pennsylvania. Differences in species composition, diversity, and temporal distribution are compared among sites.

Melanagromyza dianthereae (Malloch) (Agromyzidae) is a stem borer of *J. americana*, but no detailed data on the immature stages are available (Malloch 1920, Spencer and Steyskal 1986). Therefore, we present observations on the general biology of this species.

Materials and Methods

Three sites in three watersheds were sampled during the summer of 1996. Little Beaver Creek, in Beaver Creek State Park (OH, Columbiana Co.) is an intermediate order stream, 20 to 30 m wide in the sampling area. The canopy shaded less than 10% of the stream. *Justicia americana* grew in shallow water along each bank, but only the southern bank was sampled as it was easily accessible and supported the densest growth. The second site was an unnamed tributary of the Connoquenessing Creek (hereafter referred to as Harmony Creek) located near Harmony (PA, Butler Co.). This was the smallest stream sampled, ranging from 12–15 m in width, and had a canopy coverage of approximately 75%. *Justicia americana* grew throughout the stream but was densest near the banks. The third site was Wolf Creek, located approximately 4 km northeast of Slippery Rock University (PA, Butler Co.). This stream ranged from 15–20 m in width, and the canopy coverage was less than 25%. Wolf Creek supported a dense growth of *J. americana* along the banks and within the stream channel (Fig. 1).

The visually densest monocultural stands of *J. americana* were sampled at each site. On each sampling date, six 10 m transects were walked in 10 paces, with one back and forth swing with a standard aerial sweep net (30.5 cm diameter) executed per pace. The acalyptrate Diptera were aspirated from the net, brought back to the laboratory, frozen at approximately −10° C overnight, and subsequently pinned and labeled. Additional specimens were collected by general sweeping with an aerial net.

Three pan traps per site per sampling date were placed within the densest stands of *J. americana* after sweep sampling was completed. The 20 × 15 × 4 cm pans were painted yellow (Disney et al. 1982), and each end tied to a plant stem with string. Approximately 1.5 cm of water to which a drop of liquid detergent was added was placed in the pans. Pans were left for approximately 24 h. Trapped insects were stored in 70% ethanol and identified but were not included in the quantitative data, as most pans became inundated due to fluctuating water levels, currents, or human disturbance.

As a measure of diversity, the Shannon-Weaver Index (Pielou 1966) was used because it incorporates both species richness and evenness. Separate measures of diversity (s), richness (H′), and evenness (J′) were calculated for each site. Sorensen's Index of Similarity ($S = 2C/[A + B]$) was used to compare the degree of similarity of the dipteran assemblages between each site, where A and B are the numbers of species found at the two sites compared, and C is the number of species each site has in common (Sorensen 1948). A value of zero indicates complete dissimilarity, whereas 1.00 indicates complete similarity. Although some of the acalyptrates encountered have an unknown or questionable association with *J. americana* (see below), all species obtained during quantitative sampling were included in these calculations.

To obtain data on the biology of *M. dianthereae*, plants were collected from Beaver Creek on 3 July (n = 28), 21 July (n = 33), and 9 August (n = 20), and from Harmony Creek on 7 July (n = 47), placed in a large cooler with stream water to keep the rhizomes moist, and transported back to the laboratory. We split open stems, and any immature stages present were placed in breeding jars or preserved in 70% ethanol. Observations of stem damage by larvae were recorded. To obtain eggs, we placed portions of stem in 0.5 cm of water within breeding jars with field-collected females. Breeding jars were kept in the laboratory at 20° C in a 14:10 light:dark photoperiod.

Specimens of Diptera obtained have been deposited in the personal collection of JBK, the Carnegie Museum of Natural History (Pittsburgh, PA), and the Ohio Biological Survey's Museum of Biological Diversity (Columbus, OH).

Results

A total of 747 acalyptrate Diptera of 28 species and 23 genera was collected. Each site yielded a different assemblage of species (Table 1). Beaver Creek had the highest species richness with 28 species, followed by Harmony Creek and Wolf Creek with 16 and 12, respectively (Fig. 2). Ephydridae dominated (68.5%) with 512 specimens of 10 species and 7 genera. Adults of *M.*

Fig. 1. *Justicia americana* growing in Wolf Creek.

Table 1. Species of acalyptrate Diptera collected from *J. americana* at each site.

Species	Beaver	Wolf	Harmony
Agromyzidae			
Cerodontha dorsalis Malloch	X		X
Melanagromyza dinathereae (Malloch)	X	X	X
Phytoliriomyza spp.	X		X
Chloropidae			
Apotropina hirtoides (Sabrosky)	X	X	X
Chlorops certimus Adams	X		X
Elachiptera erythropleura Sabrosky	X		X
Eribolus nanus (Zetterstedt)	X		X
Gaurax spp.	X		
Thaumatomyia glabra (Meigen)	X		
Drosophilidae			
Drosophila macrospina Stalker and Spencer	X	X	
D. palustris Spencer	X		
Scaptomyza spp.	X	X	
Ephydridae			
Athyroglossa granulosa (Cresson)	X	X	X
Discocerina obscurella (Fallén)	X	X	X
Hydrellia griseola (Fallén)	X	X	X
Notiphila carinata Loew	X	X	
Ochthera anatolikos Clausen	X	X	X
Parydra aquila (Fallén)	X		
P. quadrituberculata Loew	X	X	X
P. unitubercula Loew	X		
Scatella favillacea Loew	X		X
S. picea (Walker)	X	X	X
Zeros flavipes Williston	X		
Sciomyzidae			
Dictya steyskali Valley	X		X
Sepedon armipes Loew	X	X	X
S. pusilla Steyskal	X		
Sphaeroceridae	X	X	X
Tephritidae			
Euaresta bella (Loew)	X		

dianthereae represented 14.3% of the total acalyptrates collected. All species obtained in pan traps were also collected with an aerial net.

Hydrellia griseola, *Notiphila carinata*, and *Parydra quadrituberculata* represented 87.7% of the total Ephydridae collected, with 449 specimens (60.1% of total acalyptrates). Each species was encountered during quantitative sweeping at each site with the exception of *N. carinata*, of which only several specimens were taken during general sweeping at Harmony Creek. *Hydrellia griseola* was the most abundant ephydrid collected (43.9% of all Ephydridae), followed closely by *P. quadrituberculata* (40.5%).

Changes in total numbers of acalyptrates did not follow any consistent pattern among sites. The number of flies collected at Beaver Creek peaked in early July (Fig. 3a). Wolf Creek had a relatively constant number of flies throughout the summer (Fig. 3b). In contrast, numbers were low at Har-

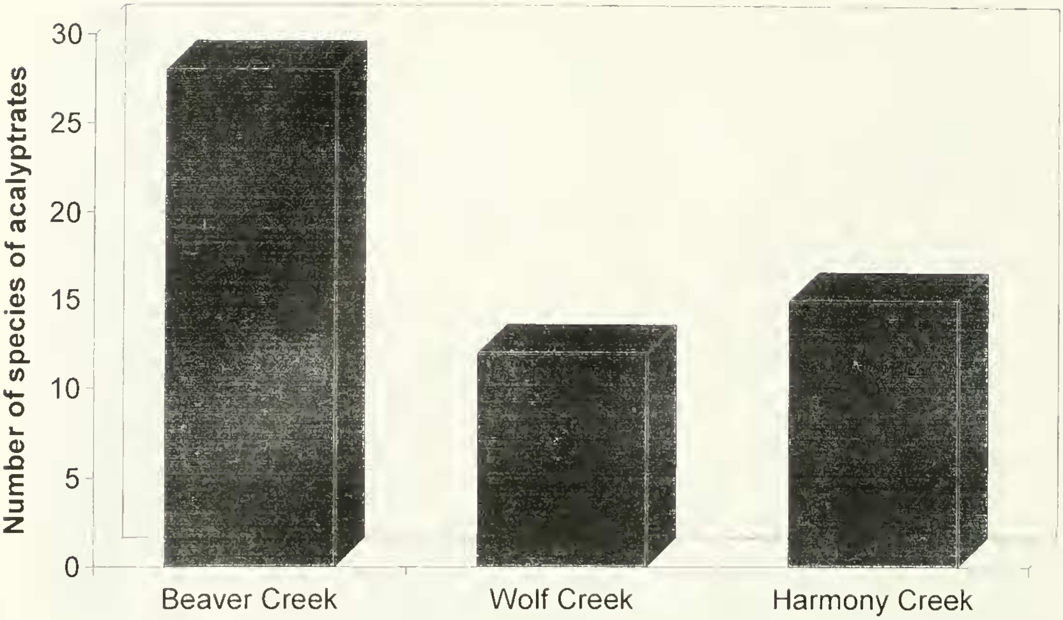

Fig. 2. Number of acalyptrate species collected from each site.

mony, but increased sharply on 24 August (Fig. 3c).

Values of species diversity (s), species richness (H′), and evenness (J′) are given in Table 2. Similarity (S) of Beaver Creek vs. Wolf Creek was 0.60, Beaver Creek vs. Harmony Creek was 0.73, and Wolf Creek vs. Harmony Creek was 0.64.

The total number of species collected at Beaver Creek peaked in early July (Fig. 3a), with Wolf Creek and Harmony Creek each exhibiting a similar but less dramatic trend (Fig. 3b, c). Total Ephydridae followed essentially the same trends as total individuals at each site (Fig. 4a–c), as did ephydrid species diversity (Fig. 4a–c). Numbers of *H. griseola* and *P. quadrituberculata* also followed the same trends as total individuals. Compared to total individuals, *N. carinata* exhibited a delay in maximum numbers at Beaver Creek, was collected in low numbers at Wolf Creek, and was absent in quantitative sweeps at Harmony Creek. The other abundant species, *M. dianthereae,* was abundant only at Beaver Creek where it peaked in early July. This species remained at relatively low and constant numbers at the other two sites (Fig. 5a–c).

Biology of Melanagromyza dianthereae

Spencer and Steyskal (1986) reported that *M. dianthereae* had been taken in Illinois, Indiana, and Maryland. Our records from Ohio and Pennsylvania are, to our knowledge, the first for these states.

Of 128 plants examined, 55 (42.97%) contained larvae or puparia, or had stem damage consistent with that of *M. dianthereae.* The stems of plants with larval mines had slightly enlarged areas, usually between the first and second nodes. These swollen areas were periodically inundated as water levels fluctuated.

Larval mines were in the center of the stem, inside the plant's outer vascular bundles. The central area of mined stems remained intact, as each contained a single pith core that larvae did not consume. Mines measured approximately 20.0 × 3.0 mm when puparia were present. The anterior end of larvae and puparia faced the apex of the plant. Prior to pupation, larvae created a small channel from the mine to

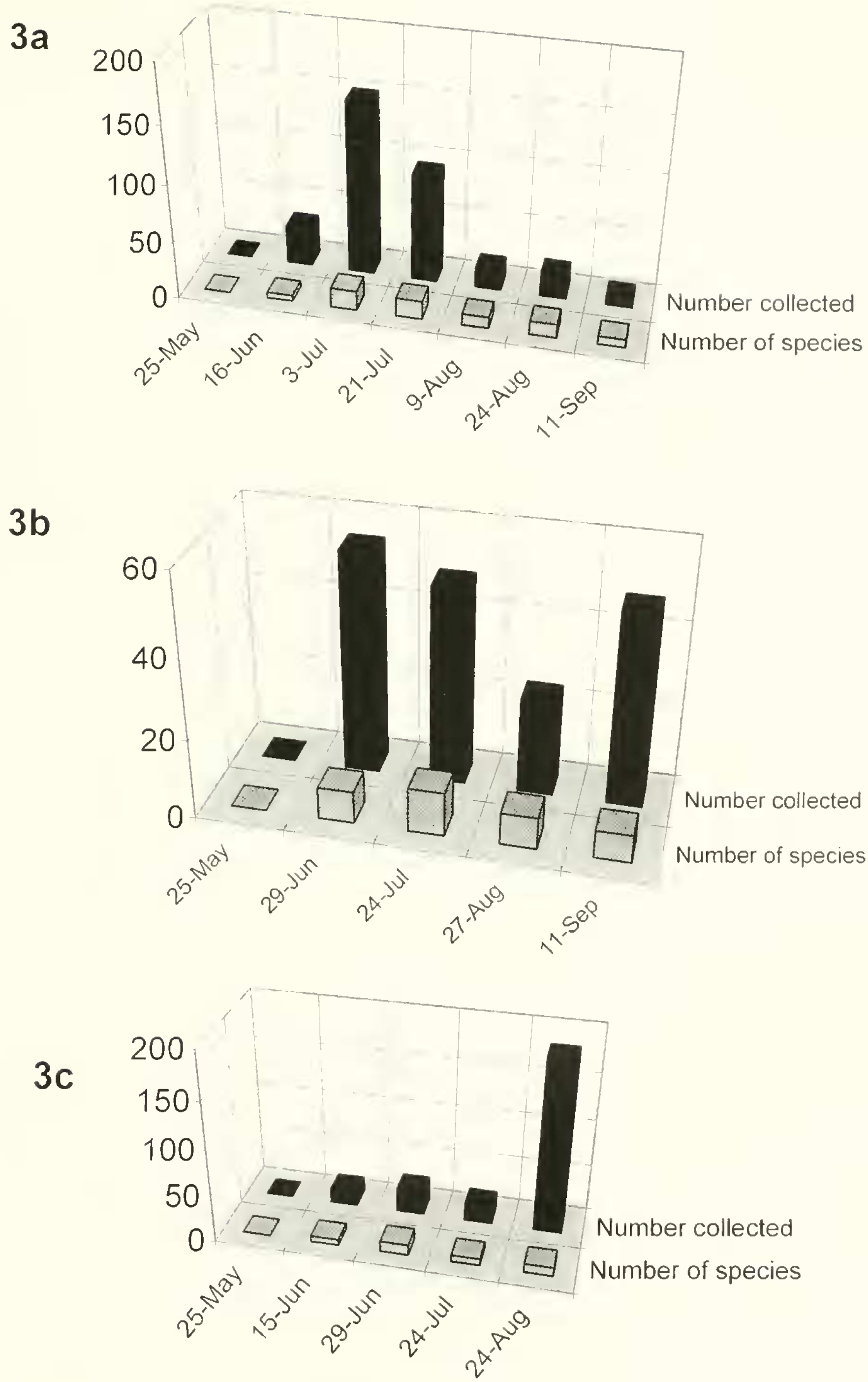

Fig. 3. Numbers and species of acalyptrates collected at Beaver Creek (a), Wolf Creek (b), and Harmony Creek (c).

Table 2. Values for species diversity (s), richness (H′), and evenness (J′) of the acalyptrate Diptera collected at each site.

	s	H′	J′
Beaver Creek	28	1.00	0.31
Harmony Creek	16	0.74	0.24
Wolf Creek	12	0.92	0.34

the epithelial layer of the stem. Puparia were found within these channels. Mines with puparia alone had exit holes in the epithelium of the stem at the end of the channel.

A puparium collected on 9 August was entirely pale, suggesting that it had recently metamorphosed. By 21 August, a well-developed fly was seen through the transparent pupal skin. The adult emerged 27 August. The pupal period thus was approximately 19 days at laboratory temperatures.

A male and female placed in a breeding jar were observed to copulate several times during a 48 h period. The female laid 37 eggs on the stem and was occasionally observed to have her head under water while she grasped the stem. The abdomen was above the water surface while eggs were attached to the stem.

Because no eggs hatched, the incubation period was not determined. No more than three eggs were found on any one field-collected plant.

Several puparia yielded undetermined parasitic wasps (Hymenoptera: Braconidae), all apparently conspecific. One pupa of *M. dianthereae* collected 7 July (Harmony site, from below the first node of the plant stem) exhibited internal damage, although the pupal skin was intact. One adult wasp was observed through the pupal skin to move out of the posterior end of the developing fly, but remained within the puparium until it emerged 8 July.

Discussion

Life history information on *Melanagromyza dianthereae* (Malloch 1920, Spencer and Steyskal 1986, this study) and the absence of this species from stands of adjacent riparian vegetation (Keiper, pers. obs.) indicate that it is probably a specialist stem-borer of *J. americana. Notiphila carinata* is a detritivore found in anoxic sediments, and pierces roots of *J. americana* (its only known host) with respiratory spiracles to obtain oxygen (Deonier et al. 1979). *Hydrellia griseola* is a polyphagous leaf miner (Deonier 1971) that has not been reported to attack *Justicia.* However, we encountered many adults during quantitative sampling (n = 197) and in the surviving pan traps, suggesting that it is indeed associated with this macrophyte. *Cerodontha dorsalis* and *Phytoliriomyza* spp. also have phytophagous larvae (Spencer and Steyskal 1986), but we obtained no evidence associating them with *J. americana* as a host plant.

Stands of *J. americana* cause deposits of sand and sediment to accumulate, resulting in the formation of semi-aquatic habitats. Larvae of *P. aquila, P. unituberculata,* and *P. quadrituberculata* consume diatoms (Deonier and Regensburg 1978, Thier and Foote 1980) and are associated with the deposits of diatom-laden sediments. Larvae of *Scatella* spp. feed on algae and Cyanobacteria (Foote 1977, Zack and Foote 1978, Connell and Scheiring 1981), and their food sources undoubtedly also flourish among the roots and rhizomes.

Discocerina obscurella, A. hirtoides, Gaurax spp., and Sphaeroceridae are detritivores and may take advantage of the deposits of decaying material among the stems and rhizomes. *Athyroglossa granulosa* is also a scavenger, but has been reared only from decaying skunk cabbage (*Symplocarpus foetidus* (L.) Nutt.) (Grimaldi and Jaenike 1983). Larvae of *Scaptomyza* spp. have been described as generalists, feeding on fungi, rotting leaves, and fermenting fruit (reviewed by Ferrar 1987).

Predators encountered include *O. anatolikos,* the adults and larvae of which prey on a variety of insects (cf., Simpson 1975). The snail-killing Sciomyzidae encountered probably fed on snails within the stands.

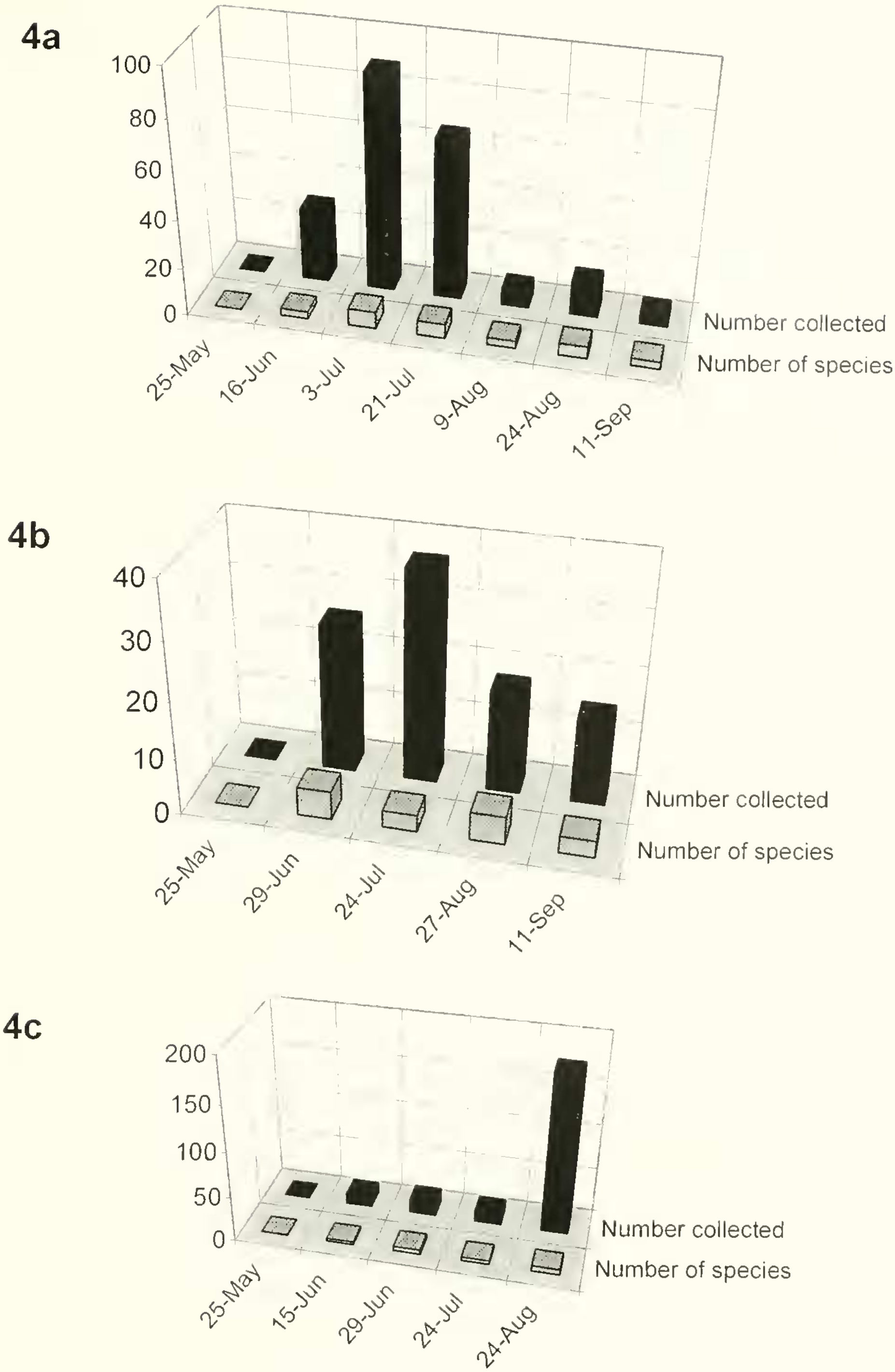

Fig. 4. Numbers and species of Ephydridae collected at Beaver Creek (a), Wolf Creek (b), and Harmony Creek (c).

Dictya steyskali and *S. armipes* are known to feed on aquatic pulmonate snails (Gastropoda: Pulmonata) in shallow water (Neff and Berg 1966, Valley and Berg 1977). *Thaumatomyia glabra* preys on root aphids (Homoptera) infesting sugar beets (Parker 1918, as *Chloropisca glabra* Meigen), and is therefore probably an incidental.

Other acalyptrates encountered undoubtedly do not have a direct association with *J. americana*, but may benefit from its presence as a refuge or source of nectar. The tephritid *E. bella* is a seed predator of common ragweed (*Ambrosia artemisiifolia* L.) (Foote et al. 1993), and *C. certimus* a stem borer of sedges (Cyperaceae) (Rogers et al. 1991). *Zeros flavipes* was reported from damp soil near the edges of ponds (Scheiring and Connell 1979), but it is unknown whether this species inhabits the wet sediment deposits around water willow. *Elachiptera erythropleura* is a secondary invader of damaged monocots (Valley et al. 1969) and general detritivore (Wendt 1968), whereas *E. nanus* is a secondary invader of *Carex* (Cyperaceae) (Valley et al. 1969). Possible associations between *J. americana* and the remaining acalyptrates remains unknown.

Todd and Foote (1987a) suggested that the structural complexity of yellow water lily, *Nuphar lutea* L., provides hiding places from predators, protection from adverse weather conditions, and oviposition sites. *Justicia americana* probably provides these benefits as well. Plants grow to approximately 1 m tall, and produce dense stands which completely cover the water and substrate under the plants in many areas. Herbivores, detritivores, and algivores are represented, and the predators mentioned above probably hunt within the spatially complex stands. Thus, water willow supports a multi-trophic dipteran community.

Although Ephydridae constituted over a third (n = 11) of the total number of species recorded from *J. americana*, this number is much lower than the numbers of species of shore flies associated with other wetland plants. For instance, Todd and Foote (1987a) recorded 13 species from *Sparganium eurycarpum* Engelm., 14 from *Eleocharis smallii* Britt., 14 from *Typha latifolia* L., and 21 from *N. lutea*. Ten species of *Notiphila* alone were encountered in *N. lutea*, whereas only one has been recorded from *J. americana*. Since both *J. americana* and *N. lutea* are dicotyledons, we speculate that flowing water constitutes a selective pressure that relatively few acalyptrates have overcome. Therefore, aquatic macrophytes growing in lotic environments may be used less by acalyptrate Diptera than those in still water. Habitat instability has been implicated with a reduction in the species richness of Diptera (e.g. Steinly 1986).

The temporal pattern of species diversity was very similar among the three sites, with very few species encountered at the beginning of the summer, a peak in diversity during late June and July, and a modest drop in numbers as summer progressed (Fig. 3a–c). Somewhat surprisingly, the species assemblages were quite different at each site as indicated by Table 1 and the intermediate values of S. The temporal distribution of the dominant species also varied among sites (Fig. 5a–c). The most anomalous data were collected at Harmony Creek. Why did the numbers of *H. griseola* and *P. quadrituberculata* explode at the end of the summer, and why were so few *N. carinata* obtained here? Beaver Creek and Wolf Creek were more pristine areas than Harmony Creek, which was bordered by a housing development on one side and a golf course on the other. Perhaps *N. carinata* is sensitive to human disturbances. Beaver Creek was the largest stream, and harbored the highest numbers of *N. carinata*. Perhaps more sediments are deposited among the plants, providing an enhanced habitat for this species. These observations suggest that, although sites may support similar vegetation, the acalyptrate Diptera community may be dissimilar in species composition, proportions, and temporal distribution.

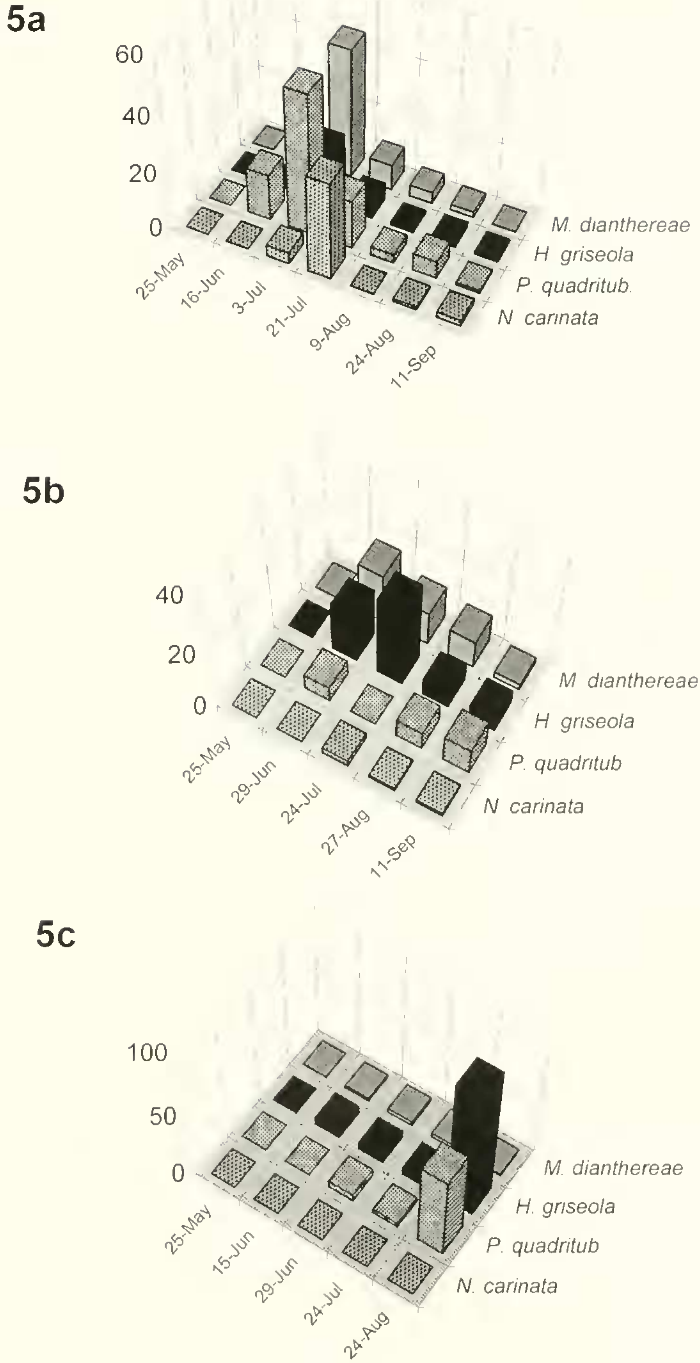

Fig. 5. Total number of dominant acalyptrate Diptera from Beaver Creek (a), Wolf Creek (b), and Harmony Creek (c).

We suggest that surveys of the acalyptrate Diptera associated with *Justicia americana* be conducted in other areas of North America for comparison to our data. Our sites were less than 100 km from each other, yet we found notable differences among them. Comparisons of sites further away would give insight into differences in the phenology and composition of species from geographically isolated stands of this widespread constituent of some lotic communities.

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